A STUDY VEGETATION DYNAMICS in Northern Eurasia climate system on the base of coupled model ocean-atmosphere-vegetation-soil under global climate changes: Scenario A2.

V. Krupchatnikoff, V., Yu. Martynova
(ICMMG SB RAS, Novosibirsk, Russia/SibHRI, Novosibirsk, Russia
E-mail: vkrup@ommfao1.sscc.ru)

Background

In northern Eurasia, which includes the areas of tundra, boreal forests, semideserts, and deserts, there is a wide variety of the functional types of vegetation and climatic conditions. This region plays an important role in the exchange of energy, moisture, and greenhouse gases between the atmosphere, the underlying surface, and the hydrosphere.

•The biosphere, which includes the surface air layer, the vegetation layer (ecosystems and biomes), soil, and the hydrosphere, has a noticeable influence on atmospheric climate through the mechanisms of exchange of energy, moisture, momentum, greenhouse gases, and aerosol.

•Variations in the composition and structure of the surface biosphere result in variations in the fluxes of the substances indicated above and, thus, in climate changes. One can say that the climate and surface hydrology of northern Eurasia, which are formed mainly under the influence of ecosystems, make a significant contribution to global climate changes due to the mechanisms of feedbacks between vegetation and atmospheric climate

Feedback of vegetation are capable to increase reaction of climatic model to change of a snow cover (Barnett T., et al, 1989; Bonnan G., et al, 1992; Ganopolsky A. et al, 1998; Claussen M. et al, 2006; B. Cook et al , 2007 etc.)

It also well established that vegetation in high latitudes have significant impact on land surface albedo and albedo feedbacks to climate system. This provides the opportunity for strong feedbacks associated with coupled snow – vegetation system. Variation of the trees line can modulate the snow cover albedo feedbacks and impact on climate (B. Cook, G. Bonan, S. Levis, H. Epstein, 2007)

F. Lunkeit M. B¨ottinger K. Fraedrich H. Jansen E. Kirk
A. Kleidon U. Luksch, 2007

A dimensionless set of differential equations

(Hoskins and Simmons (1975))

$$\frac{\partial \zeta + f}{\partial t} = \frac{1}{(1-\mu^2)}\frac{\partial F_\nu}{\partial \lambda} - \frac{\partial F_u}{\partial \mu} + P_\zeta$$

$$\frac{\partial D}{\partial t} = \frac{1}{(1-\mu^2)}\frac{\partial F_u}{\partial \lambda} + \frac{\partial F_\nu}{\partial \mu} - \nabla^2 E - \nabla^2(\phi + T_0 \ln p_s) + P_D$$

$$C = \frac{\partial \phi}{\partial \ln \sigma} + T$$

$$\frac{\partial \ln p_s}{\partial t} = -\int_0^1 A\, d\sigma$$

$$\frac{\partial T'}{\partial t} = F_T - \dot{\sigma}\frac{\partial T}{\partial \sigma} + \kappa W T + \frac{J}{c_p} + P_T$$

Method

Mode splitting. Semi-implicit time scheme

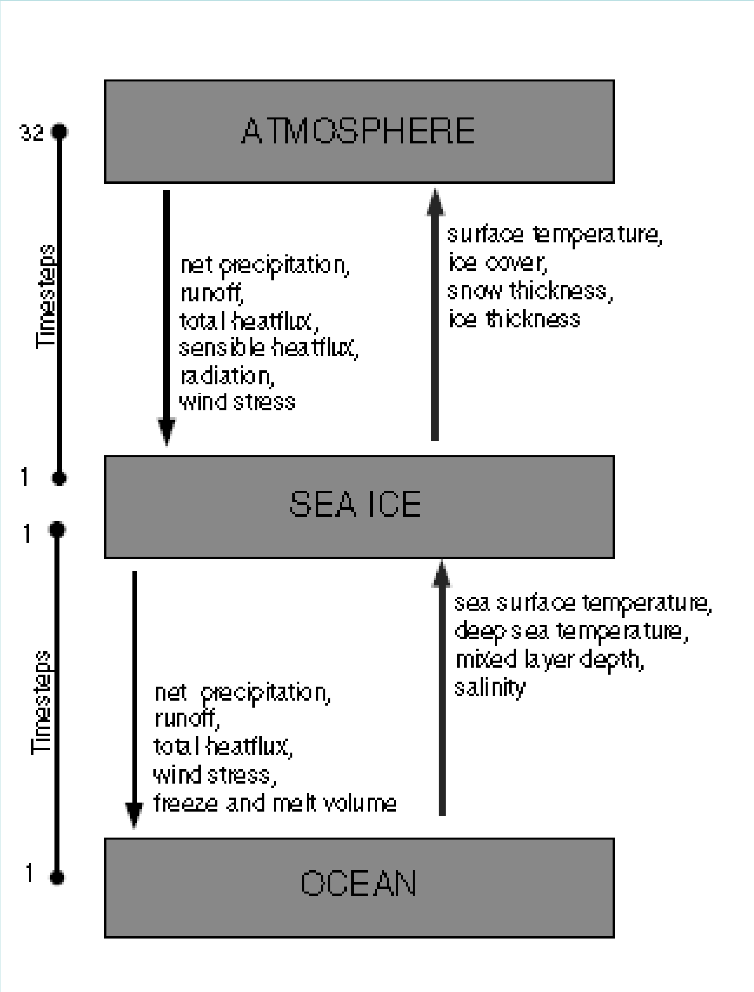
- Spectral Transform method

- Vertical discretization

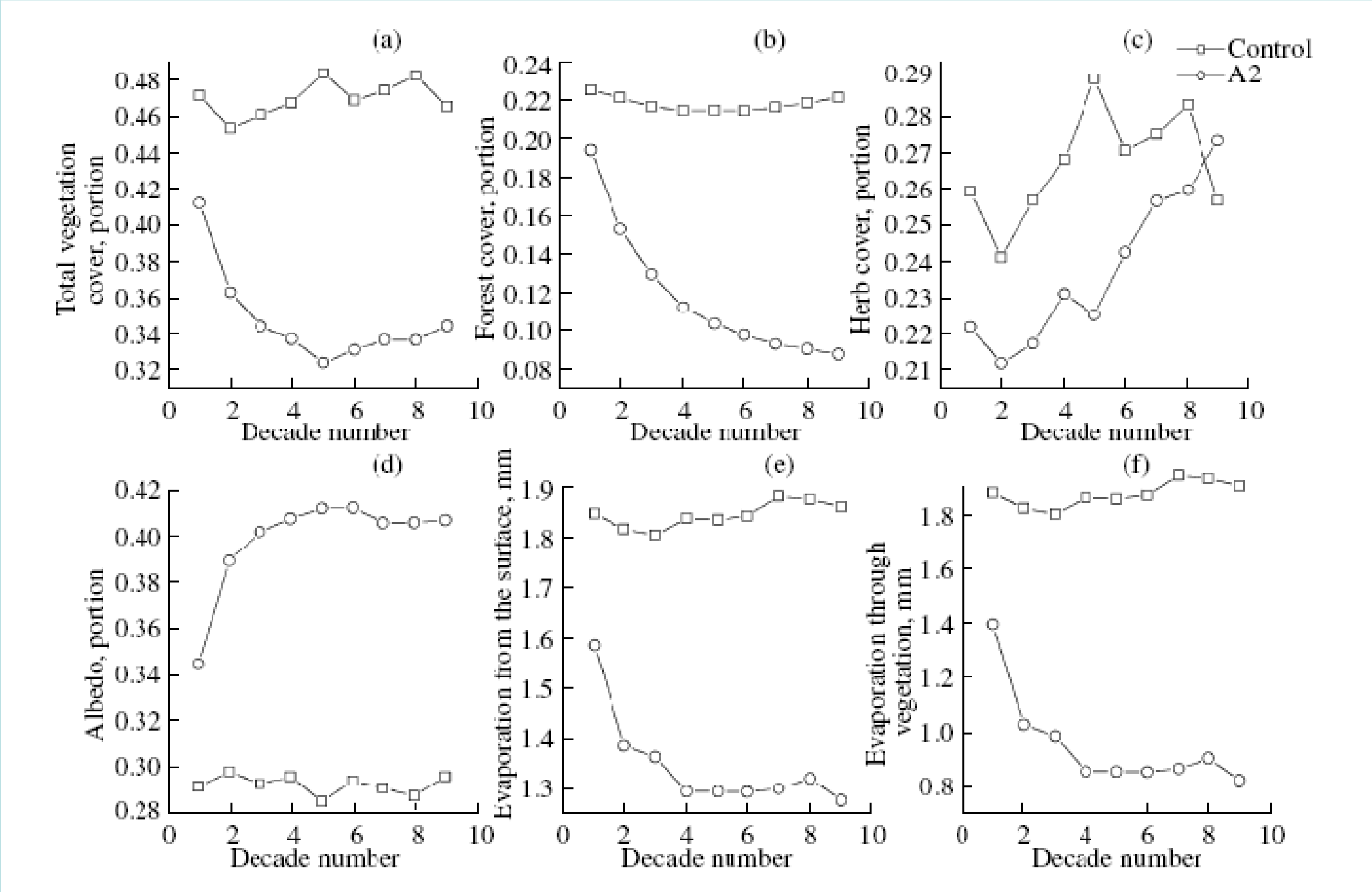
  - For the hydrostatic approximation an angular momentum conserving finite-difference scheme (Simmons and Burridge (1981)) is used

Model Physics – Parameterizations

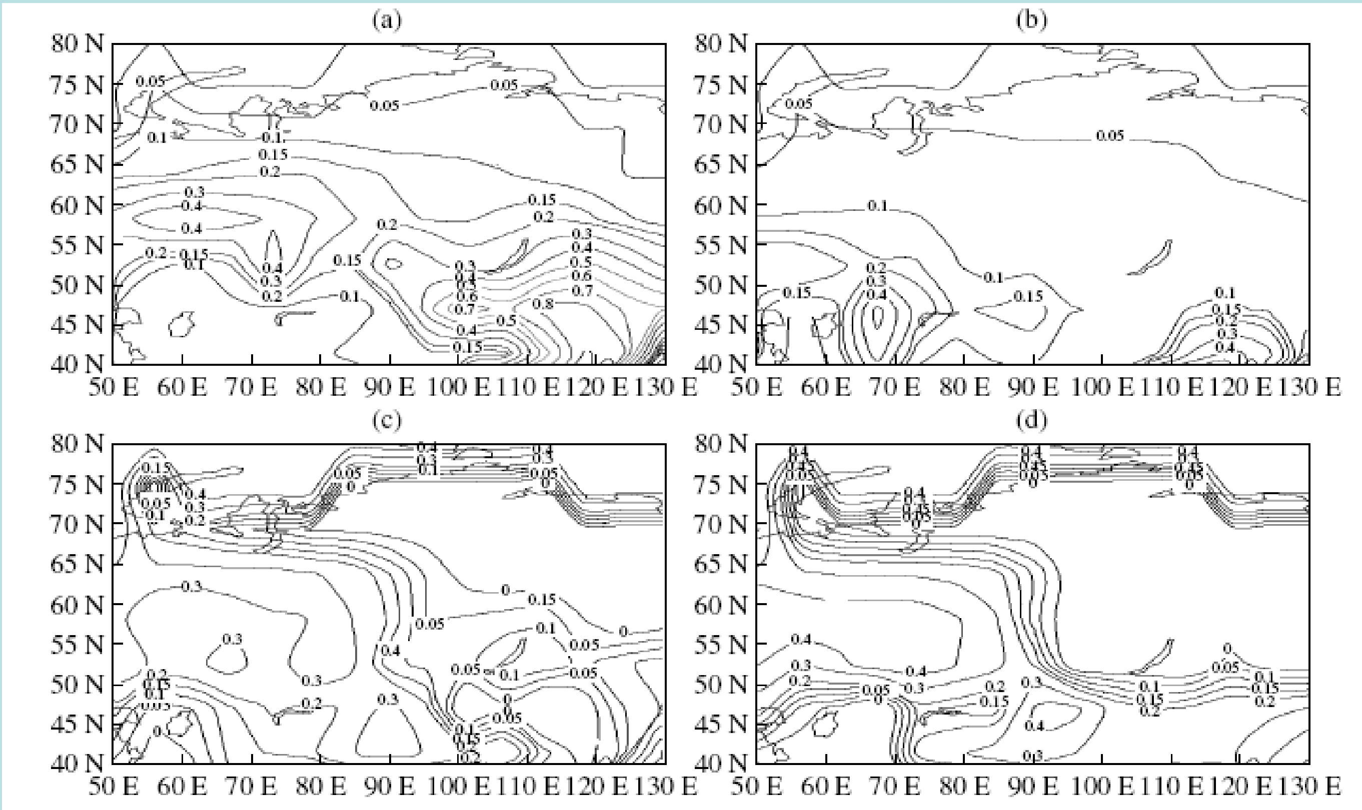
3.1 Surface Fluxes and Vertical Diffusion
3.2 Horizontal Diffusion
3.3 Radiation
3.3.1 Short Wave Radiation
3.3.2 Long Wave Radiation
3.4 Moist Processes and Dry Convection
3.5 Land Surface and Soil
3.6 Sea Surface
Ocean: Mixed Layer
Slab Ocean Model
Biosphere: SIMBA
Dynamic Vegetation
Vegetative Cover
Carbon Balance
Derivation of Land Surface Parameters
Ice


ATMOSPHERE
SEA ICE
OCEAN
32
1
1
1
Timesteps
Timesteps
net precipitation,
runoff,
total heatflux,
sensible heatflux,
radiation,
wind stress
surface temperature,
ice cover,
snow thickness,
ice thickness
net precipitation,
runoff,
total heatflux,
wind stress,
freeze and melt volume
sea surface temperature,
deep sea temperature,
mixed layer depth,
salinity

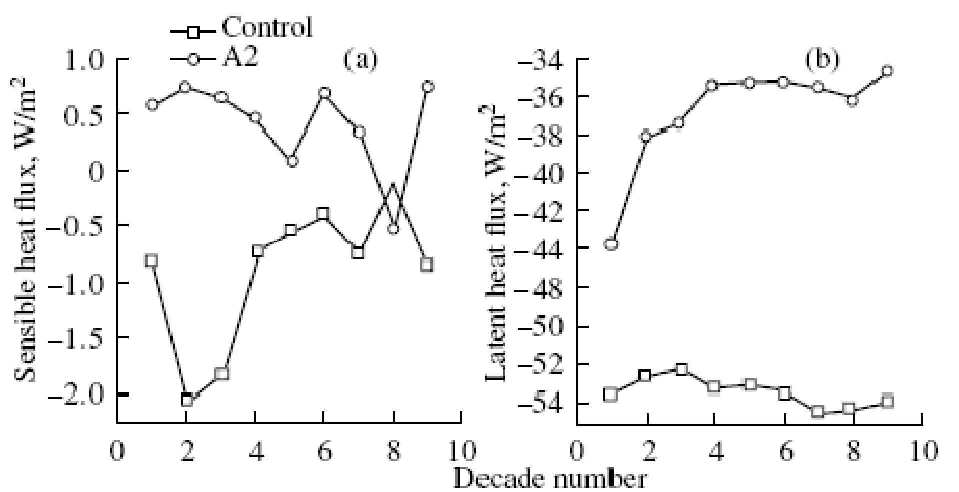
Variations in vegetation-cover parameters for the two scenarios vs. integration decade number (0–2000, 10–2100) for Siberia.



Distribution of the portions of (a) and (b) forest vegetation and (c) and (d) herb and bushes over Siberia; (a) and (c) correspond to the beginning (the first decade) of the 21st century and (b) and (d) correspond to the end (the eighth decade) of the 21st century. Scenario A2.



Variations in surface heat fluxes for the two scenarios vs. the number of integration decade (0–2000, 10–2100) for Siberia.



Evaluation of ecosystem dynamics and terrestrial carbon cycling in LPJ dynamic global vegetation model.

The model is being used to study past, present and future ecosystem Dynamics, biochemical and biophysical interaction between Ecosystem and atmosphere and as component of coupled ESM.

Table 1 PFT parameter values: z_1 and z_2 are the fraction of fine roots in the upper and lower soil layers, respectively; g_{min} is the minimum canopy conductance; r_{fire} is the fire resistance; a_{leaf} is the leaf longevity; f_{leaf}, $f_{sapwood}$, f_{root} are the leaf, sapwood and fine root turnover times, respectively; $t_{mort,min}$ is the temperature base in the heat damage mortality function and S_{GDD} is the growing degree day requirement to grow full leaf coverage

PFT	W/H*	z_1 (–)	z_2 (–)	g_{min} (mm s^{-1})	r_{fire} (–)	a_{leaf} (yr)	f_{leaf} (yr^{-1})	$f_{sapwood}$ (yr^{-1})	f_{root} (yr^{-1})	$T_{mort,min}$ (°C)	S_{GDD} (°C)
Tropical broad-leaved evergreen (TrBE)	W	0.85	0.15	0.5	0.12	2.0	0.5	0.05	0.5	–	–
Tropical broad-leaved raingreen (TrBR)	W	0.70	0.30	0.5	0.50	0.5	1.0	0.05	1.0	–	–
Temperate needle-leaved evergreen (TeNE)	W	0.70	0.30	0.3	0.12	2.0	0.5	0.05	0.5	–	–
Temperate broad-leaved evergreen (TeBE)	W	0.70	0.30	0.5	0.50	1.0	1.0	0.05	1.0	–	–
Temperate broad-leaved summergreen (TeBS)	W	0.80	0.20	0.5	0.12	0.5	1.0	0.05	1.0	–	200
Boreal needle-leaved evergreen (BoNE)	W	0.90	0.10	0.3	0.12	2.0	0.5	0.05	0.5	23	–
Boreal needle-leaved summergreen (BoNS)	W	0.90	0.10	0.5	0.12	0.5	1.0	0.05	1.0	23	100
Boreal broad-leaved summergreen (BoBS)	W	0.90	0.10	0.3	0.12	0.5	1.0	0.05	1.0	23	200
Temperate herbaceous (TeH)	H	0.90	0.10	0.5	1.00	1.0	1.0	–	0.5	–	100
Tropical herbaceous (TrH)	H	0.90	0.10	0.5	1.00	1.0	1.0	–	0.5	–	100

*W = Woody; H = Herbaceous.

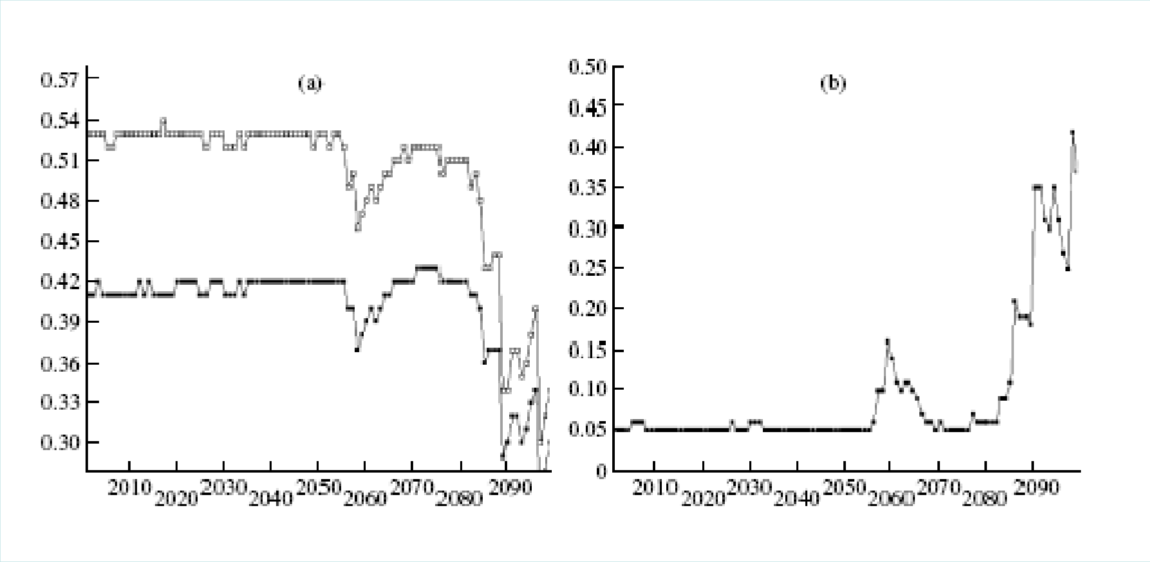
Table 2 PFT Bioclimatic limits: $T_{c,min}$ = minimum coldest-month temperature for survival; $T_{c,max}$ = maximum coldest-month temperature for establishment; GDD_{min} = minimum degree-day sum (5 °C base) for establishment; $T_{w-c,min}$ = minimum warmest minus coldest month temperature range

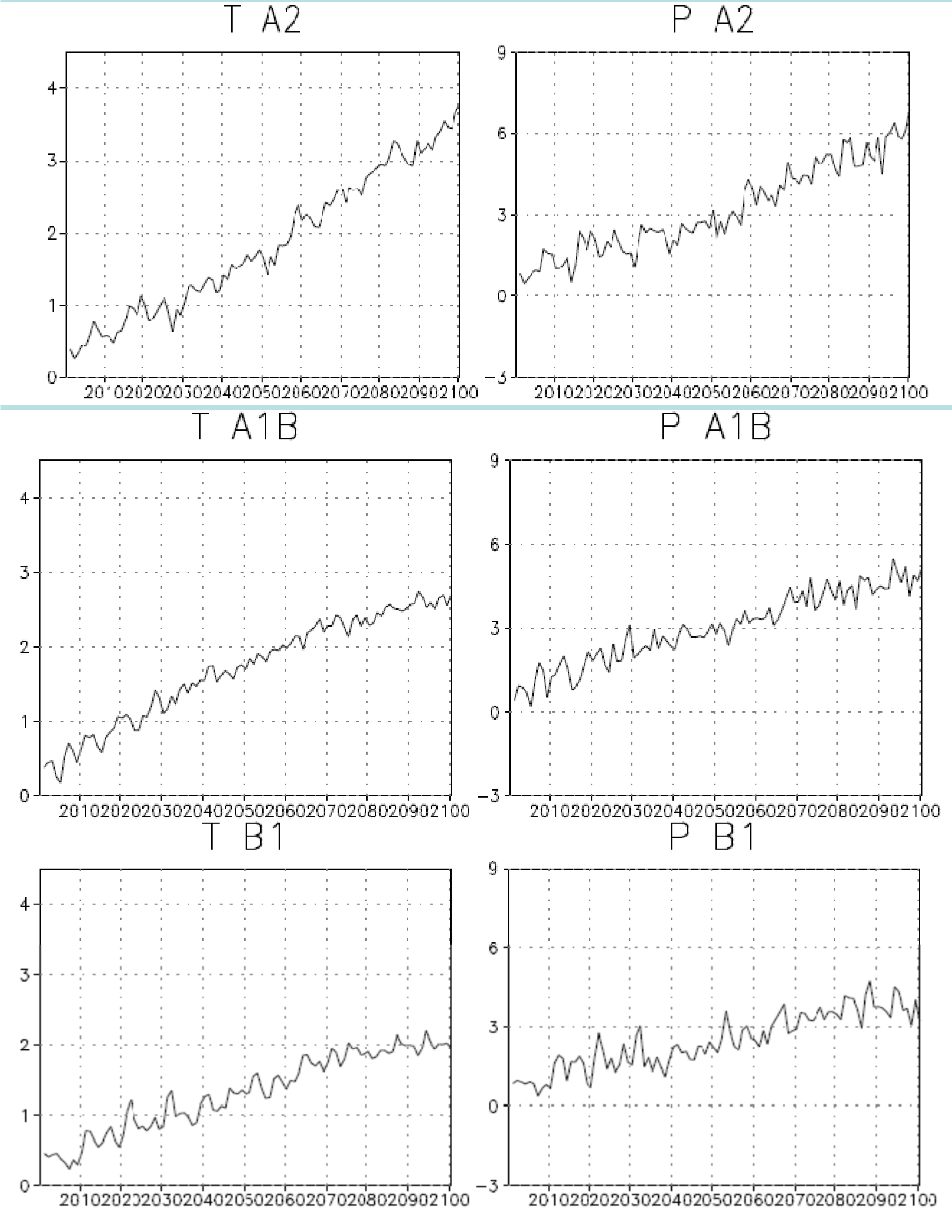
PFT	$T_{c,min}$ (°C)	$T_{c,max}$ (°C)	GDD_{min} (°C)	$T_{w-c,min}$ (°C)
Tropical broad-leaved evergreen	15.5	–	–	–
Tropical broad-leaved raingreen	15.5	–	–	–
Temperate needle-leaved evergreen	−2.0	22.0	900	–
Temperate broad-leaved evergreen	3.0	18.8	1200	–
Temperate broad-leaved summergreen	−17.0	15.5	1200	–
Boreal needle-leaved evergreen	−32.5	−2.0	600	–
Boreal needle-leaved summergreen	–	−2.0	350	43
Boreal broad-leaved summergreen	–	−2.0	350	–
Temperate herbaceous (TeH)	–	15.5	–	–
Tropical herbaceous (TrH)	15.5	–	–	–

Table 3 Parameters and constants in model equations

Function	Symbol	Value	Units	Description
Structure	k_{allom1}	100		Parameter in Eq. (4)
	k_{allom2}	40		Parameter in Eq. (3)
	k_{allom3}	0.5		Parameter in Eq. (3)
	$k_{la:sa}$	8000		Parameter in Eq. (1)
	CN_{leaf}	29		Leaf C:N ratio
	$CN_{sapwood}$	330		Sapwood C:N ratio
	CN_{root}	29		Root C:N ratio
	k_{rp}	1.6		Parameter in Eq. (4)
	CA_{max}	15	m^2	Maximum woody PFT crown area
	lr_{max}	1 (0.75)		Leaf to root ratio under non-water stressed conditions (value for herbaceous)
Phenology	T_{base}	5 (2)	°C	Minimum temperature for summergreen PFT leaf growth (value for BoNS)
	ω_{min}	0.35		Minimum water stress factor for drought deciduous PFTs
Photosynthesis	pO_2	20.9	kPa	O_2 partial pressure
	p	100.0	kPa	Atmospheric pressure
	θ	0.7		Co-limitation (shape) parameter
	$\lambda_{max,c4}$	0.4		Optimal c_i/c_a for the tropical herbaceous
	$\lambda_{max,c3}$	0.8		Optimal c_i/c_a in C_3 plants (All PFTs except TrH)
	α_{c3}	0.08		Intrinsic quantum efficiency of CO_2 uptake in C_3 plants
	α_{c4}	0.053		Intrinsic quantum efficiency of CO_2 uptake in C_4 plants
	a_{c3}	0.015		Leaf respiration as a fraction of Rubisco capacity in C_3 plants
	a_{c4}	0.02		Leaf respiration as a fraction of Rubisco capacity in C_4 plants
Plant Respiration	r	0.066 (0.011)	$g\,C\,g\,N^{-1}\,d^{-1}$	Tissue respiration rate at 10 °C (value for TrBE, TrBR)
Water Balance	α_m	1.4		Empirical constant in the evaporative demand function
	g_m	5.0		Empirical constant in the evaporative demand function
	E_{max}	5.0	$mm\,d^{-1}$	Maximum transpiration rate
	k_{melt}	3.0	$mm\,°C^{-1}\,d^{-1}$	Rate of snow melt
Mortality	k_{mort1}	0.01	yr^{-1}	Asymptotic maximum mortality rate
	k_{mort2}	0.3		Parameter in Eq. (32)
	$fuel_{min}$	200.0	$g\,C\,m^{-2}$	Minimum fuel load for fire spread
	m_e	0.3 (0.2)		Litter moisture of extinction (value for herbaceous PFTs)
	r_{fire}	0.12 (0.5)		Fire resistance (value for TrBR & TeBE PFTs)
Establishment	est_{max}	0.24	m^{-2}	Maximum sapling establishment rate
	$prec_{min}$	100	$mm\,yr^{-1}$	Minimum annual precipitation for successful sapling establishment
Soil and litter decomposition	f_{air}	0.7		Fraction of the decomposed litter emitted as CO_2 to the atmosphere
	f_{inter}	0.985		Fraction of soil-bound decomposed litter entering the intermediate soil pool
	f_{slow}	0.015		Fraction of soil-bound decomposed litter entering the slow soil pool
	τ_{litter}	2.86	yr	Litter turnover time at 10 °C
	τ_{inter}	33.3	yr	Intermediate soil pool turnover time at 10 °C
	τ_{slow}	1000.0	yr	Slow soil pool turnover time at 10 °C

CM3/INM-LPJ simulation. Scenario A2. Dynamics of vegetation distribution in a grid mesh (90E, 60N):
(a) boreal forest (BoNE, BoBS) and
(b) temperate herb (TeH).





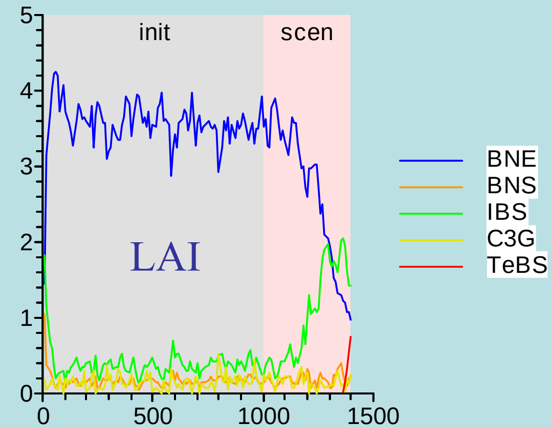
The global average temperature deviation of surface air, degrees (at the left) and precipitation (%) (on the right) for scenario A2 (above), A1B (in the middle) and B1 (below) in 2000-2100г.г. In comparison with 1980-1999г.г.

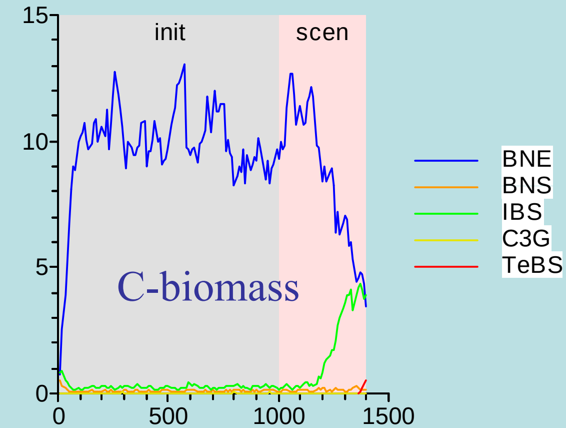
INM(CM3) model

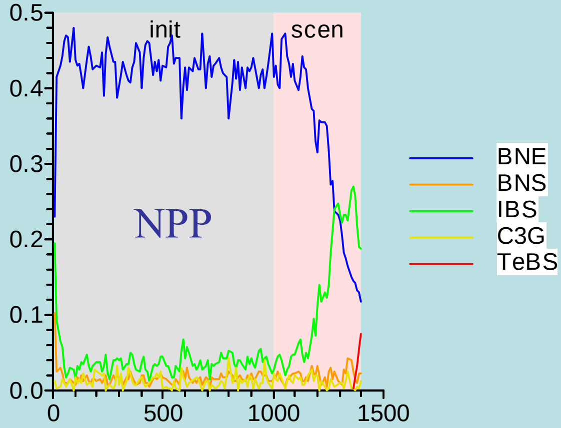
Simulation (LPJ-GUESS) for stand at (longitude 90.25, latitude 59.75)

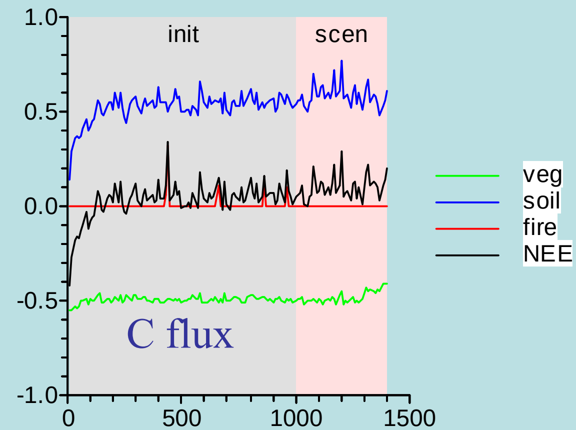
Init-Years	Hist-Years	Scen-Years	Temp-Change-degC	Prec-Change-%	CO2-Change-%
1000	0	400	14	6	100

Scenario A2





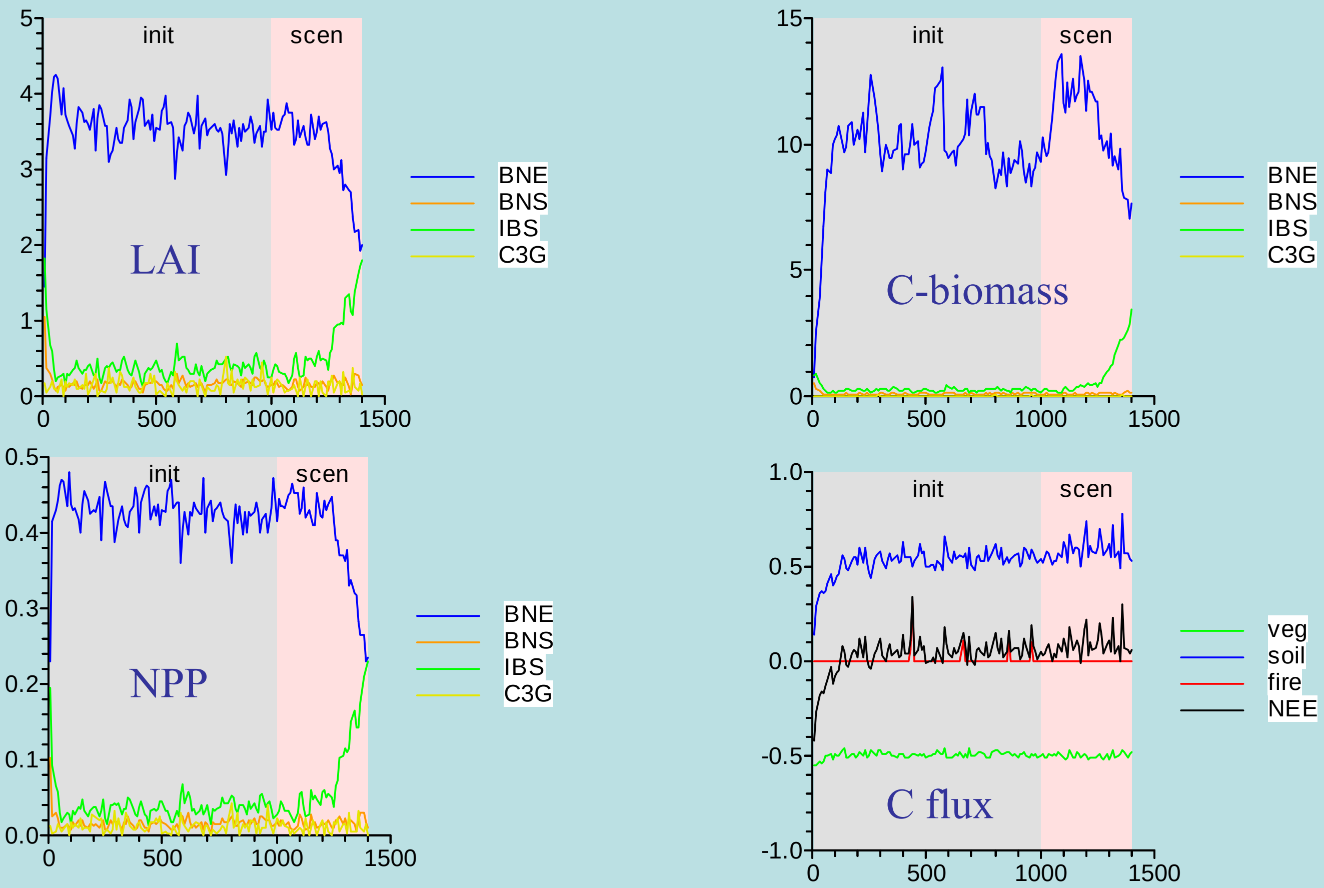




Simulation (LPJ-GUESS) for stand at (longitude 90.25, latitude 59.75)

Init-Years	Hist-Years	Scen-Years	Temp-Change-degC	Prec-Change-%	CO2-Change-%
1000	0	400	10	4.5	80

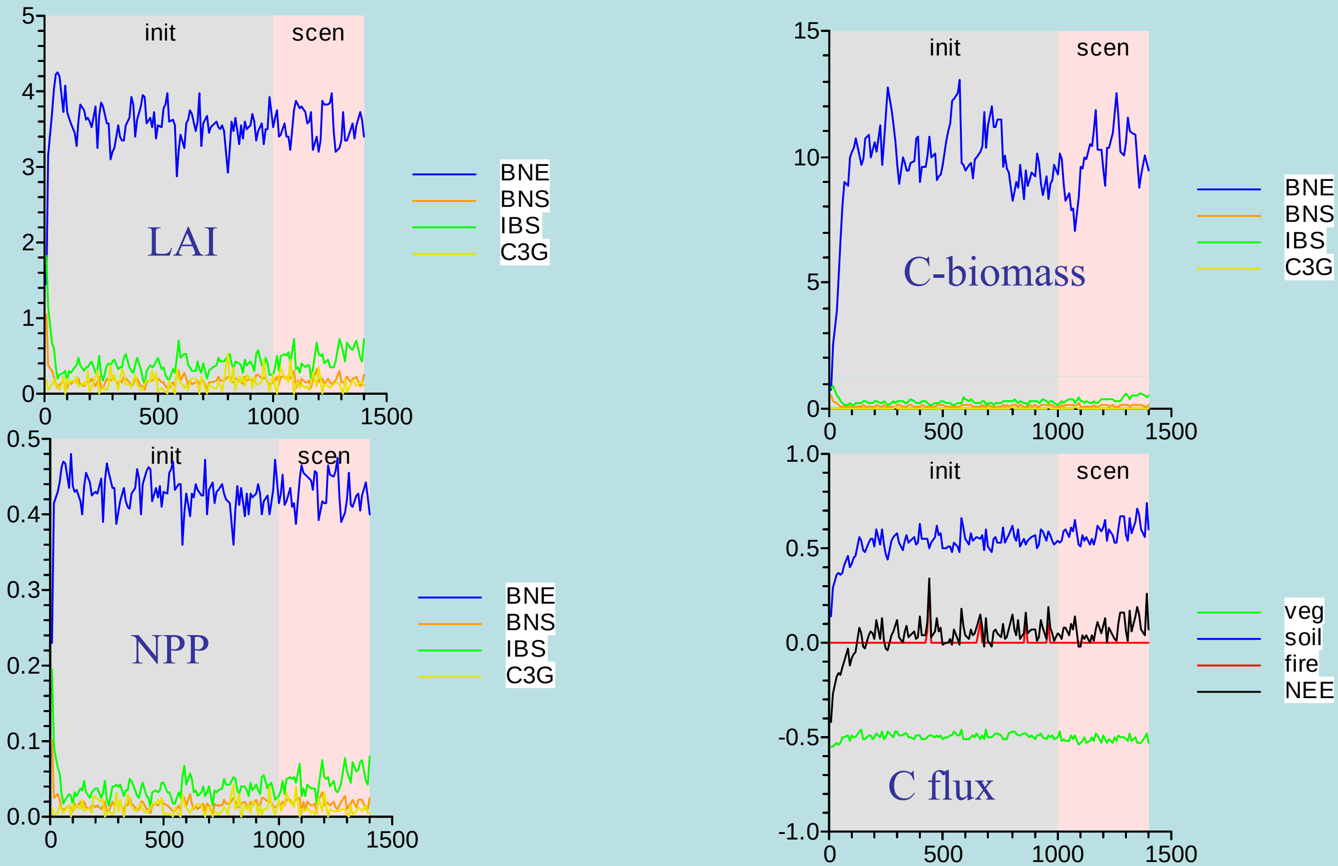
Scenario A1B



Simulation (LPJ-GUESS) for stand at (longitude 90.25, latitude 59.75)

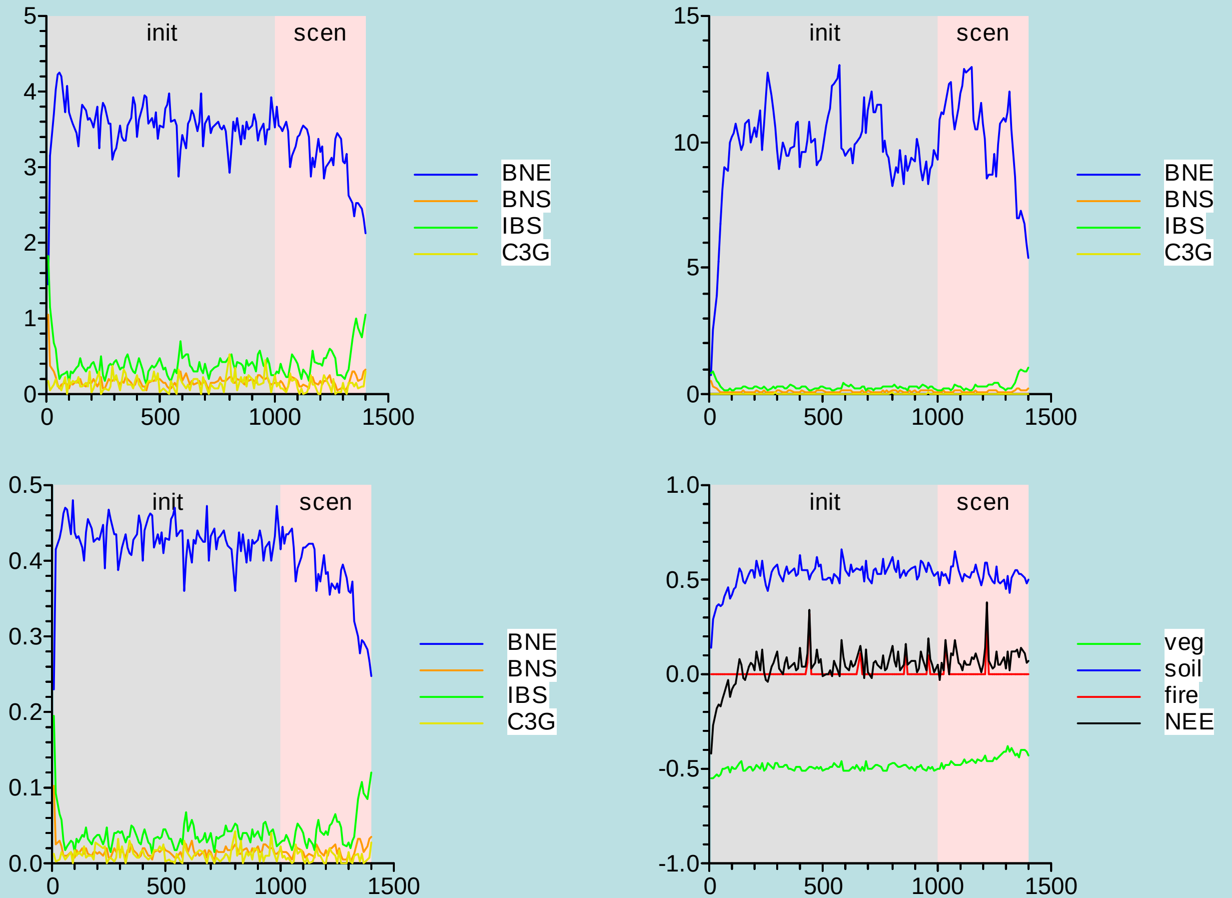
Init-Years	Hist-Years	Scen-Years	Temp-Change-degC	Prec-Change-%	CO2-Change-%
1000	0	400	6	3	50

Scenario B1



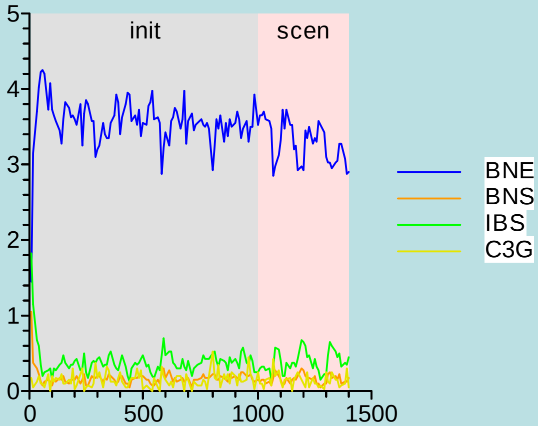
Simulation (LPJ-GUESS) for stand at (longitude 90.25, latitude 59.75)

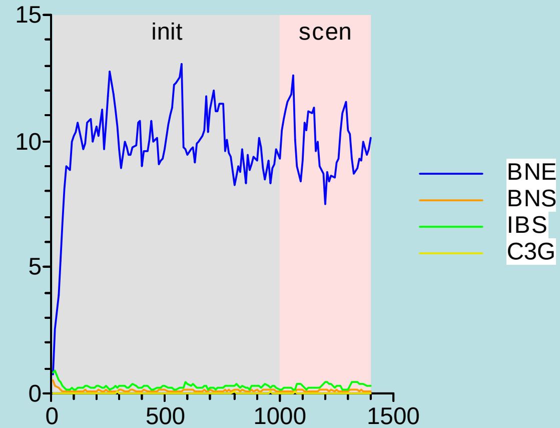
Init-Years	Hist-Years	Scen-Years	Temp-Change-degC	Prec-Change-%	CO2-Change-%
1000	0	400	8	2	0

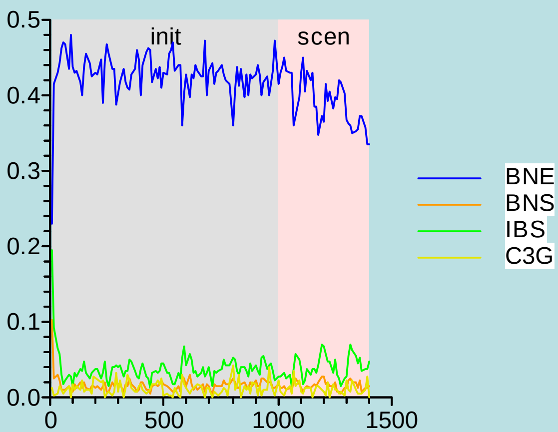


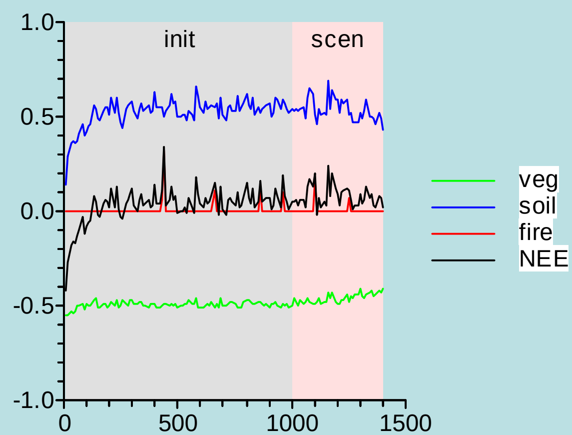
Simulation (LPJ-GUESS) for stand at (longitude 90.25, latitude 59.75)

Init-Years	Hist-Years	Scen-Years	Temp-Change-degC	Prec-Change-%	CO2-Change-%
1000	0	400	6	2	0









Conclusion

- The dynamics of vegetation in Siberia is in agreement with the dynamics of surface hydrology and with surface heat sources.

  At the end of the integration time for scenario A2, significant variations in the structure of vegetation occur in Siberia:
  - the portion of the land surface occupied by vegetation decreases from ~48% to 35%, the forest portion decreases from 20 to 10%, and the herb portion increases up to 26%. In the control experiment, at the end of the integration time, the portions of forest and herb amount to 22 and 24%, respectively.
  - In this case, albedo increased from 0.3 to 0.4, and evapotranspiration decreased by more than two times due to the decrease of the forest portion.

- The southward shift of the forest boundary and the rapid increase in the depth of snow cover in fall during the last decade of the 21st century resulted in an increase of surface albedo in Siberia (especially in winter) and in surface cooling in this region.

- Comparing the data obtained from a simulation of vegetation dynamics with model (LPJ), we obtained similar results for the evolution of the basic types of vegetation by scenario A2, A1B, B1.